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(54) **VARIABLE RADIUS SPRING DISC FOR
VEHICLE SHOCK ABSORBER**

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F16F 9/348 (2006.01)

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(2013.01); **F16F 9/3482** (2013.01); **F16F**
9/3488 (2013.01)

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1/32; F16F 1/324; F16F 1/326; F16K
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(56) **References Cited**

U.S. PATENT DOCUMENTS

5,154,263 A	10/1992	Lizell	
5,332,069 A *	7/1994	Murakami	 F16F 9/3484 188/282.6
5,497,862 A	3/1996	Hoya	
5,529,154 A	6/1996	Tanaka	
6,655,512 B2	12/2003	Moradmand et al.	
6,672,436 B1	1/2004	Keil et al.	
8,820,495 B2	9/2014	King	
2003/0094342 A1	5/2003	Dodge et al.	

(Continued)

OTHER PUBLICATIONS

International Search Report and Written Opinion dated Aug. 19,
2015 from corresponding PCT Application No. PCT/US2015/
031700 (17 pages).

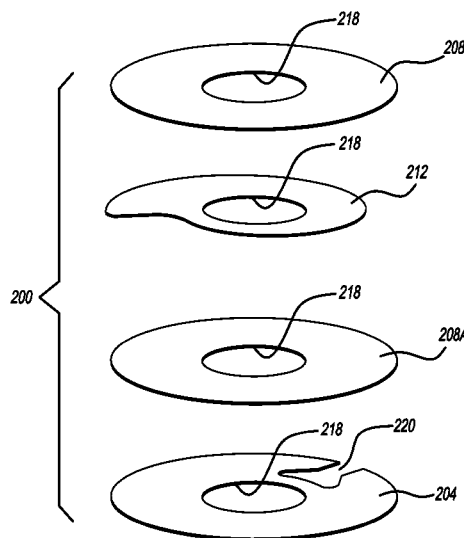
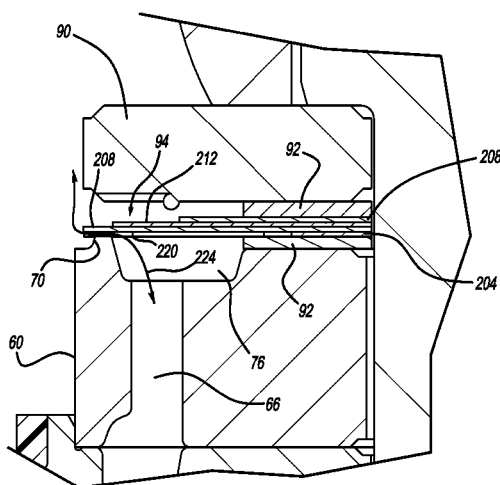
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(57) **ABSTRACT**

A shock absorber for a vehicle may include a piston and a valve disc assembly. The piston defines a plurality of passages extending through the piston between an upper working chamber and a lower working chamber of a fluid chamber. The valve disc assembly engages the piston and controls a flow of fluid between the upper working chamber and the lower working chamber through the plurality of passages. The valve disc assembly includes a variable radius spring disc among a plurality of discs. The variable radius spring disc has a varying outer radius. The valve disc assembly has a stiffness that varies circumferentially based on the variable radius spring disc such that an actuation of the valve disc assembly with respect to the piston varies circumferentially.

20 Claims, 7 Drawing Sheets



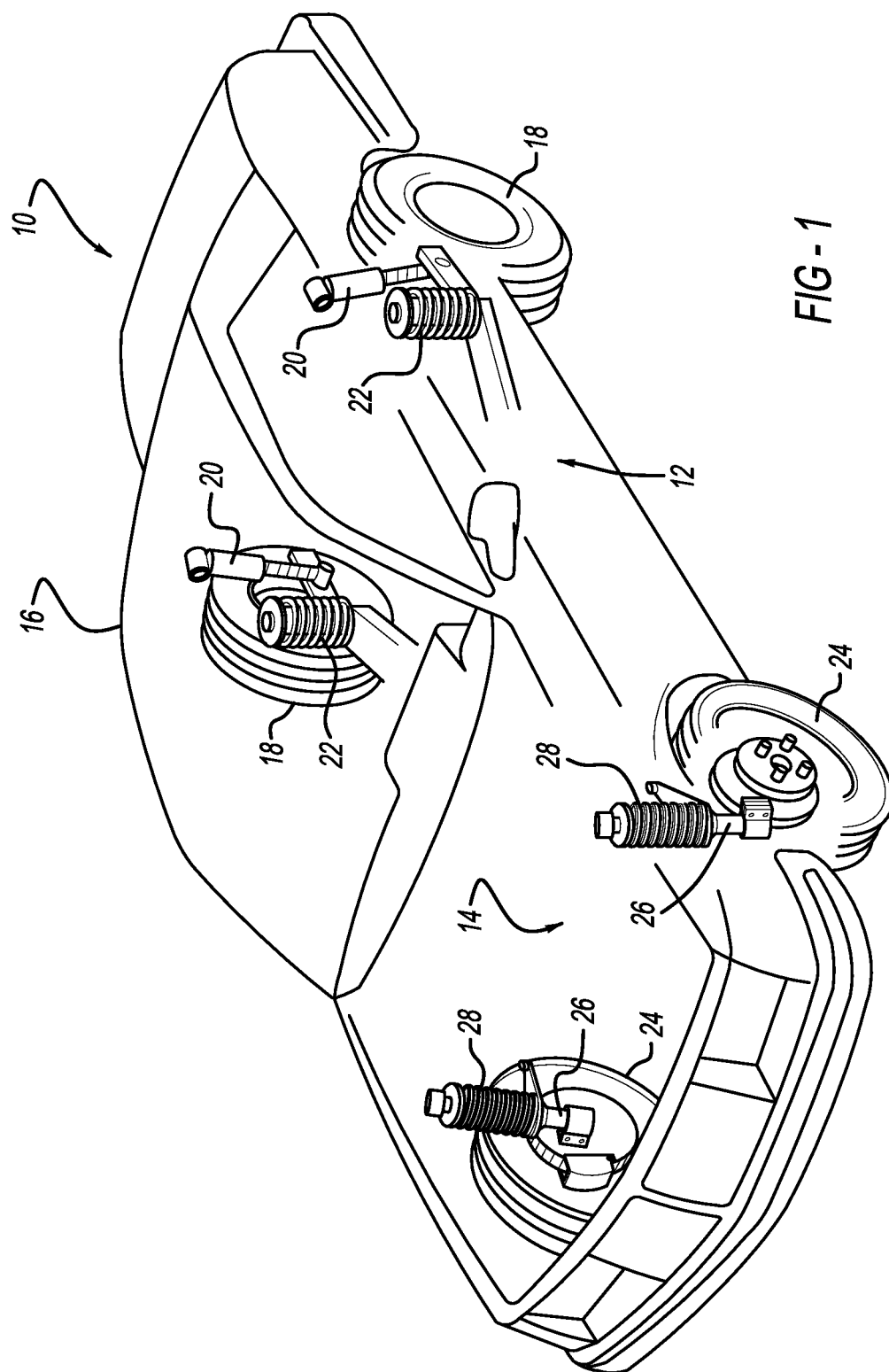
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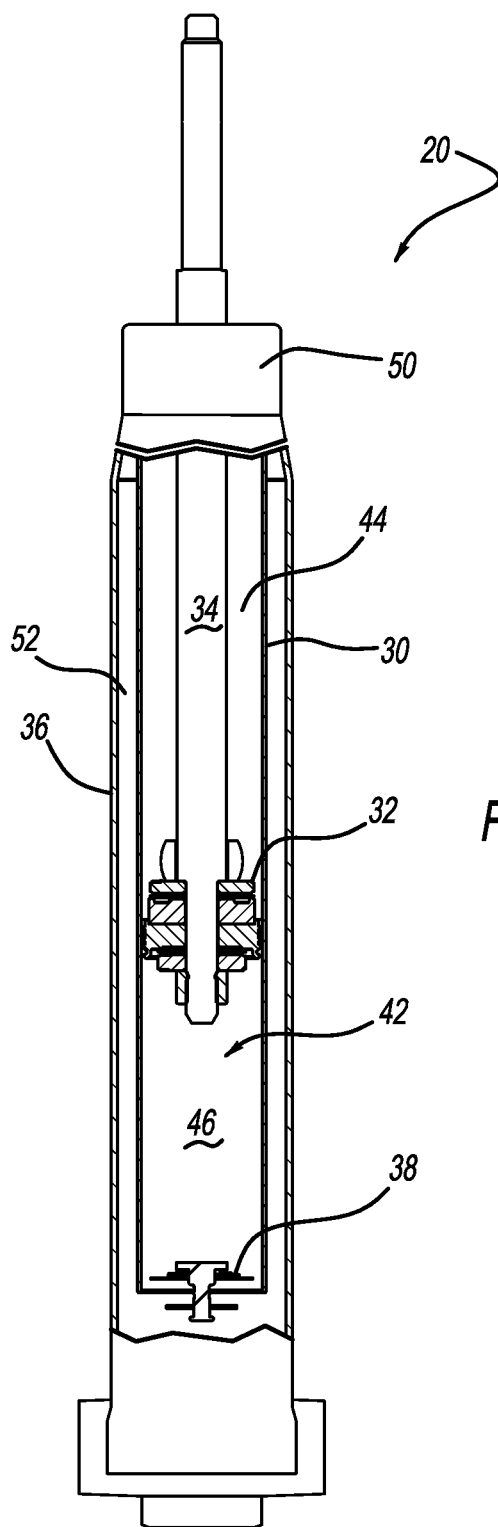
References Cited

U.S. PATENT DOCUMENTS

2008/0149438	A1	6/2008	Chikamatsu et al.	
2009/0260938	A1	10/2009	Hikosaka	
2009/0294232	A1	12/2009	Ashiba	
2013/0025446	A1 *	1/2013	Ashiba	F16F 9/3485 91/418
2014/0060985	A1	3/2014	Oshie et al.	

* cited by examiner





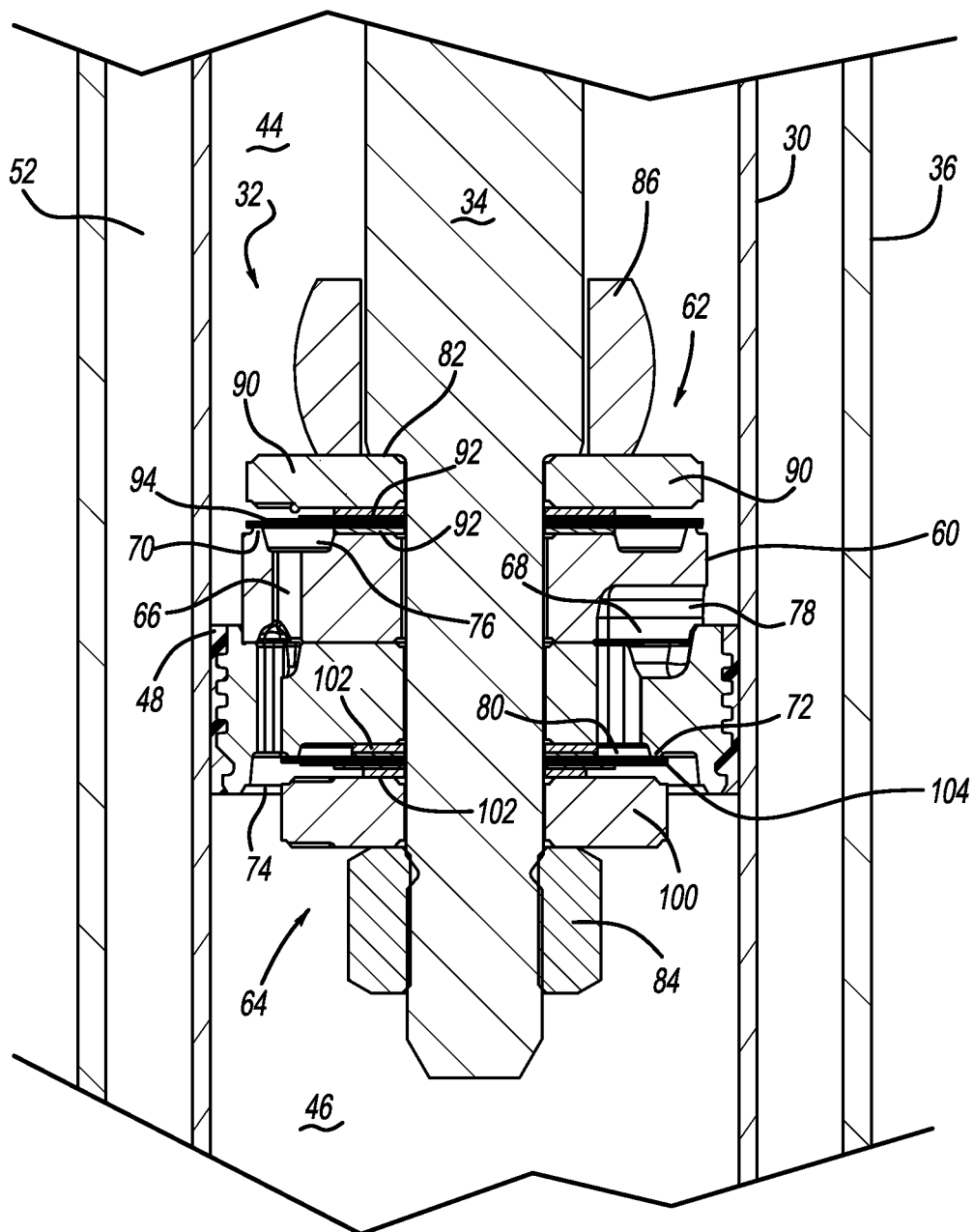


FIG - 3

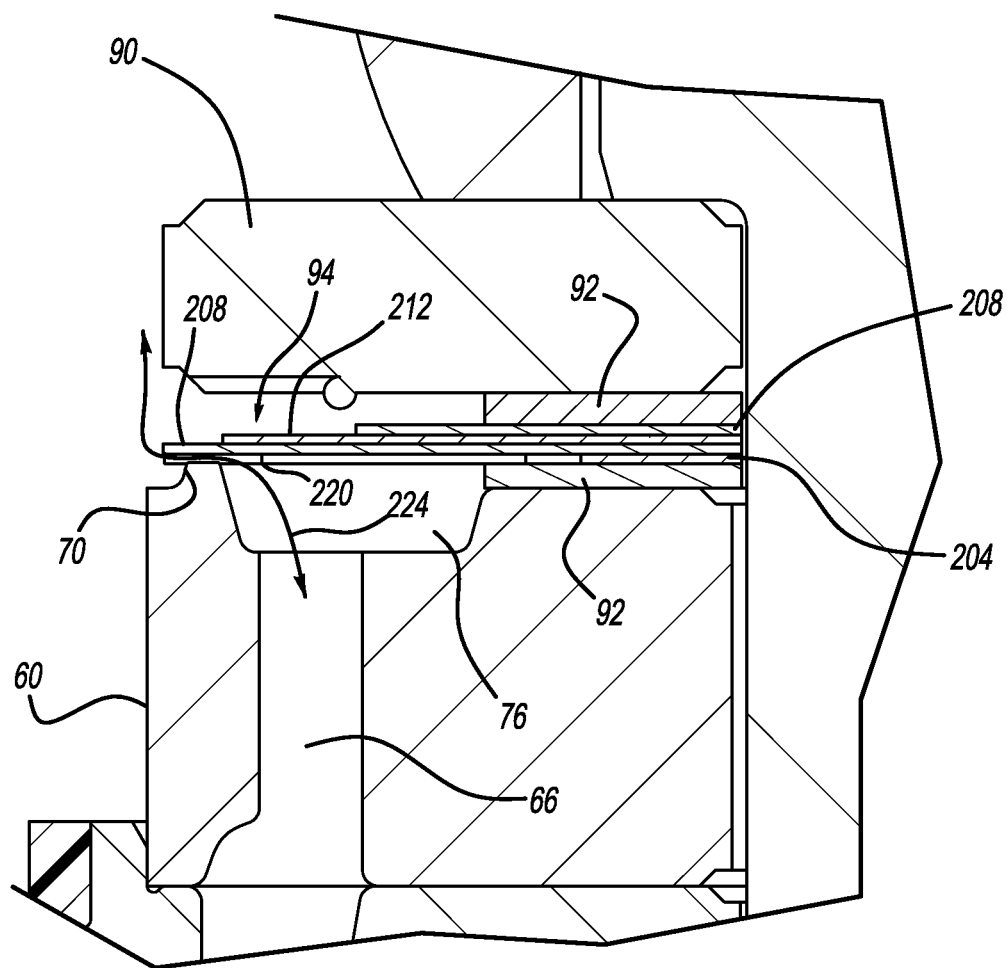


FIG - 4

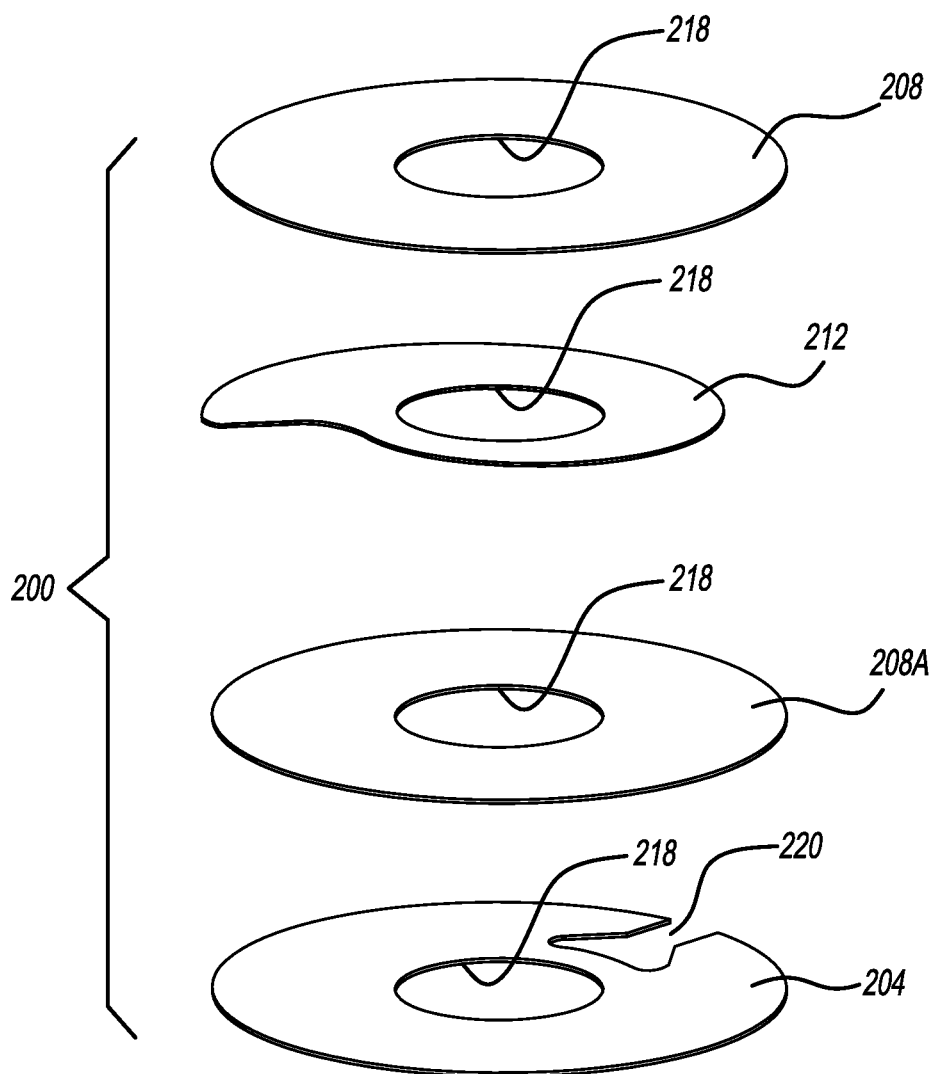
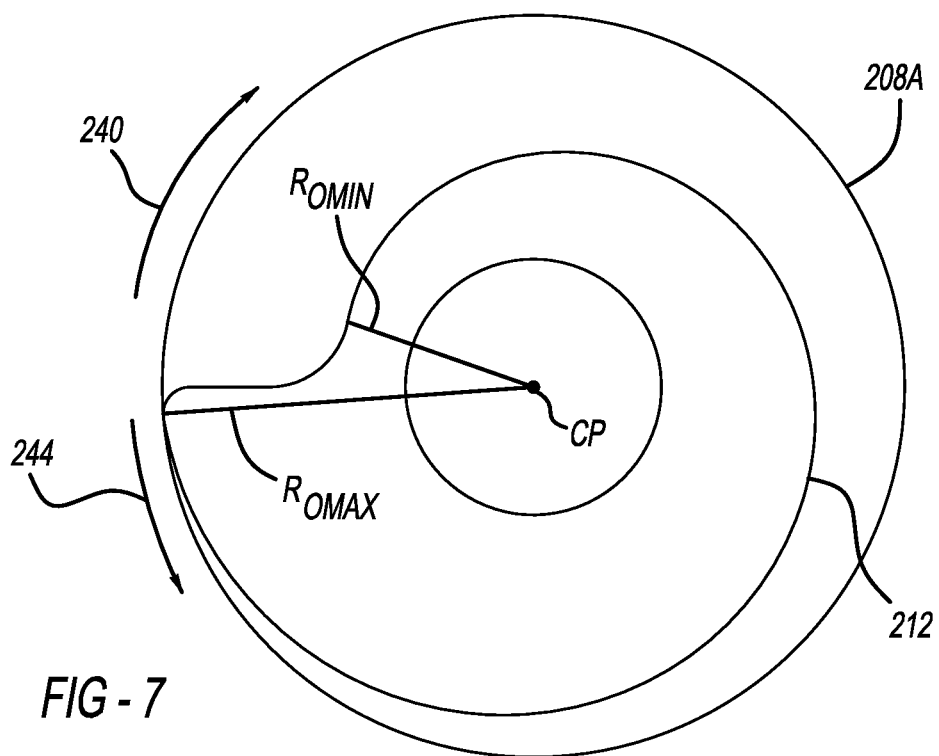
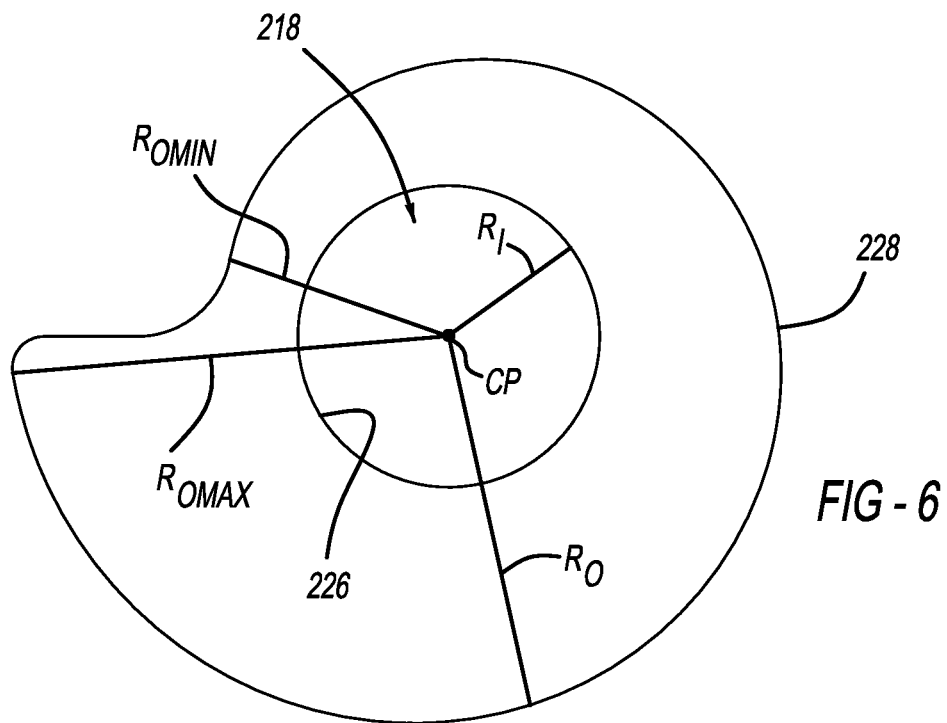
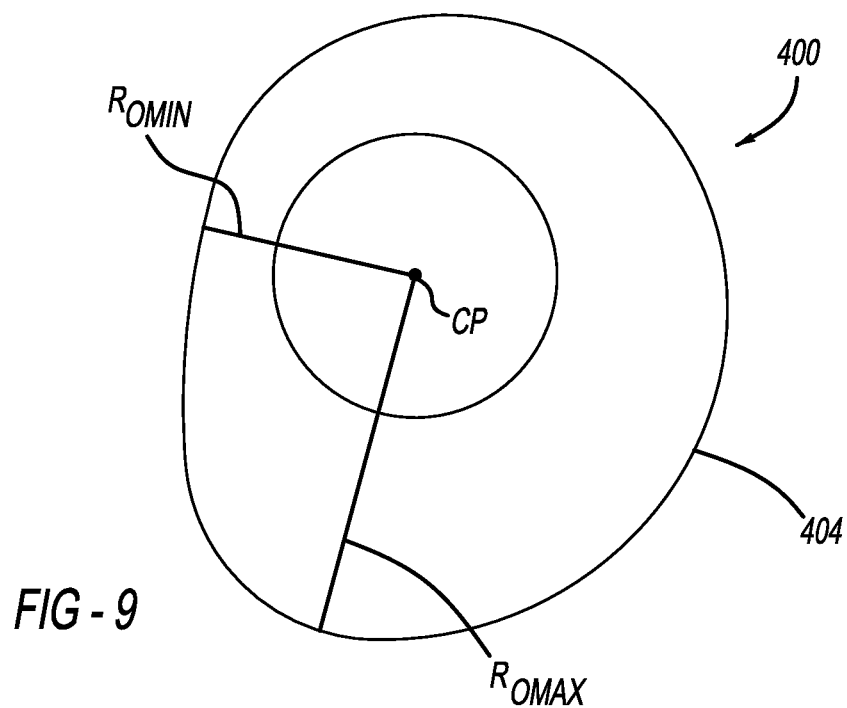
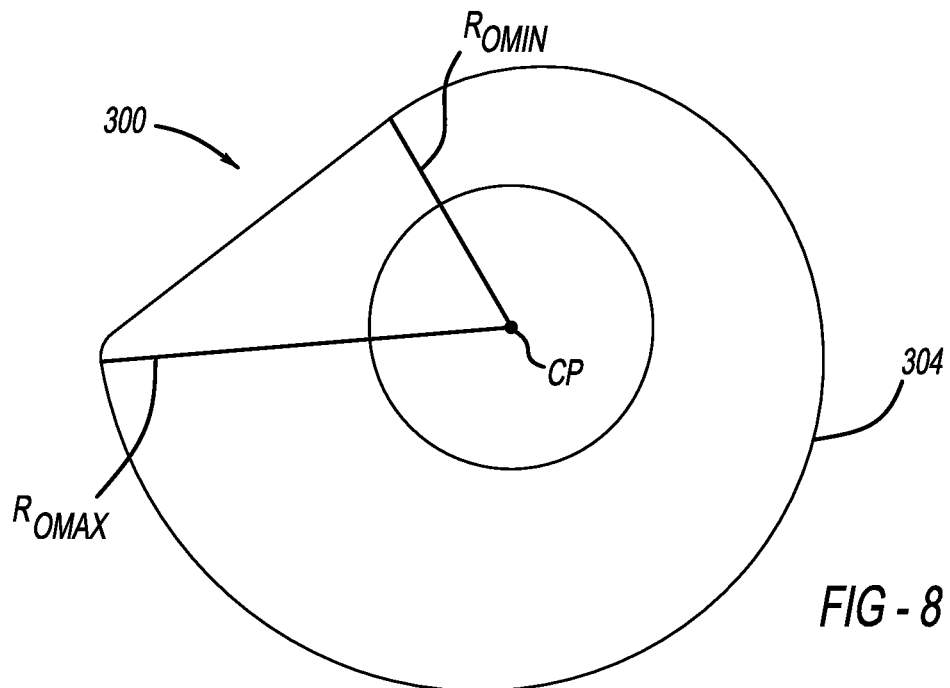


FIG - 5





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VARIABLE RADIUS SPRING DISC FOR VEHICLE SHOCK ABSORBER

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Application No. 62/000,990, filed on May 20, 2014. The entire disclosure of the above application is incorporated herein by reference.

FIELD

The present disclosure relates to shock absorbers. More particularly, the present disclosure relates to a valve disc assembly for controlling damping characteristics of a shock absorber.

BACKGROUND

This section provides background information related to the present disclosure which is not necessarily prior art.

Shock absorbers are used in conjunction with automotive suspension systems to absorb unwanted vibrations that occur during driving. To absorb the unwanted vibrations, shock absorbers are generally connected between the sprung portion (body) and the unsprung portion (suspension) of the automobile. A piston is located within a pressure tube of the shock absorber and the pressure tube is connected to the unsprung portion of the vehicle. The piston is connected to the sprung portion of the automobile through a piston rod which extends through the pressure tube.

The piston divides the pressure tube into an upper working chamber and a lower working chamber, both of which are filled with hydraulic fluid. Through valving, the piston is able to limit the flow of the hydraulic fluid between the upper and the lower working chambers when the shock absorber is compressed or extended. Accordingly, the shock absorber is able to produce a damping force that counteracts the vibration which would otherwise be transmitted from the unsprung portion to the sprung portion of the vehicle. In a dual tube shock absorber, a fluid reservoir or reservoir chamber is defined between the pressure tube and a reservoir tube. A base valve is located between the lower working chamber and the reservoir chamber to control the flow of fluid between the lower working chamber and the reservoir chamber.

Shock absorbers have been developed to provide different damping characteristics depending on the speed or acceleration of the piston within the pressure tube. Because of the exponential relationship between pressure drop and flow rate, it can be difficult to tune the damping characteristic of the shock absorber between low and high piston speeds. Specifically, the valving at the piston and/or base valve is designed to close/open in one unilateral movement, thereby causing an abrupt change in damping between low and high piston speeds.

SUMMARY

This section provides a general summary of the disclosure, and is not a comprehensive disclosure of its full scope or all of its features. The present disclosure relates to a shock absorber for a vehicle, and more particularly, to a valve disc assembly that controls the flow of fluid between an upper working chamber and a lower working chamber at varying piston speeds. The shock absorber includes a pressure tube

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that defines a fluid chamber, a piston that is disposed within the fluid chamber, and a valve disc assembly that engages with the piston. The piston divides the fluid chamber into an upper working chamber and a lower working chamber, and defines a plurality of passages that extend through the piston between the upper working chamber and the lower working chamber.

The valve disc assembly controls the flow of fluid between the upper working chamber and the lower working chamber. The valve disc assembly includes a variable radius spring disc among a plurality of discs. The variable radius spring disc has an outer radius that circumferentially varies along an outer perimeter of the variable radius spring disc. The valve disc assembly has a stiffness that varies in relation to a circumference of the variable radius spring disc such that an actuation of the valve disc assembly with respect to the piston varies circumferentially.

In a feature of the present disclosure, as fluid pressure increases in the plurality of passages, the valve disc assembly may deflect away from the piston along a direction that corresponds to an increase of the outer radius of the variable radius spring disc, and as fluid pressure decreases in the plurality of passages, the valve disc assembly may actuate to seal the passages along a direction that corresponds to a decrease of the outer radius of the variable radius spring disc.

Further areas of applicability will become apparent from the description provided herein. The description and specific examples in this summary are intended for purposes of illustration only, and are not intended to limit the scope of the present disclosure.

DRAWINGS

The drawings described herein are for illustrative purposes only of selected embodiments and not all possible implementations, and are not intended to limit the scope of the present disclosure.

FIG. 1 is a schematic representation of a typical automobile that incorporates at least one shock absorber;

FIG. 2 is a side partial cross-sectional view of a shock absorber;

FIG. 3 is an enlarged cross-sectional view of a piston assembly of the shock absorber;

FIG. 4 is an enlarged cross-sectional view of a valve disc assembly for controlling fluid through compression passages;

FIG. 5 is an exploded view of the valve disc assembly of FIG. 4;

FIG. 6 is a perspective view of a variable radius spring disc of the valve disc assembly;

FIG. 7 is a top view of the variable radius spring disc and a solid disc;

FIG. 8 is a perspective view of a variable radius spring disc in a second embodiment; and

FIG. 9 is a perspective view of a variable radius spring disc in a third embodiment.

Corresponding reference numerals indicate corresponding parts throughout the several views of the drawings.

DETAILED DESCRIPTION

The present disclosure will now be described more fully with reference to the accompanying drawings. Referring now to the drawings in which like reference numerals designate like or corresponding parts throughout the several views, FIG. 1 illustrates a vehicle 10 incorporating a sus-

pension system with shock absorbers having a variable radius spring disc in accordance with the present disclosure. The vehicle 10 includes a rear suspension 12, a front suspension 14, and a body 16. The rear suspension 12 has a transversely extending rear axle assembly (not shown) adapted to operatively support the vehicle's rear wheels 18. The rear axle assembly is operatively connected to the body 16 by means of a pair of shock absorbers 20 and a pair of helical coil springs 22. Similarly, the front suspension 14 includes a transversely extending front axle assembly (not shown) to operatively support the vehicle's front wheels 24. The front axle assembly is operatively connected to the body 16 by means of a second pair of shock absorbers 26 and by a pair of helical coil springs 28.

The shock absorbers 20 and 26 serve to dampen the relative motion of the unsprung portion (i.e., the front and rear suspensions 12 and 14, respectively) and the sprung portion (i.e., the body 16) of the vehicle 10. While the vehicle 10 has been depicted as a passenger car having front and rear axle assemblies, the shock absorbers 20 and 26 may be used with other types of vehicles or in other types of applications including, but not limited to, vehicles incorporating independent front and/or independent rear suspension systems.

Referring now to FIG. 2, the shock absorber 20 is shown in greater detail. While FIG. 2 illustrates only shock absorber 20, it is to be understood that the shock absorber 26 includes the same components as the shock absorber 20. The shock absorber 26 only differs from the shock absorber 20 in the manner in which it is adapted to be connected to the sprung and unsprung portions of the vehicle 10. Furthermore, while the shock absorber 20 is depicted as a dual-tube shock absorber, shock absorber 20 may also be a mono-tube shock absorber.

The shock absorber 20 comprises a pressure tube 30, a piston assembly 32, a piston rod 34, a reservoir tube 36, and a base valve assembly 38. The pressure tube 30 defines a working chamber 42. The piston assembly 32 is slidably disposed within the pressure tube 30, and divides the working chamber 42 into an upper working chamber 44 and a lower working chamber 46. A seal 48, which is shown in FIG. 3, is disposed between the piston assembly 32 and the pressure tube 30 to permit sliding movement of the piston assembly 32 with respect to the pressure tube 30 without generating undue frictional forces as well as sealing the upper working chamber 44 from the lower working chamber 46.

The piston rod 34 is attached to the piston assembly 32 and extends through the upper working chamber 44 and through an upper end cap 50 which closes the upper end of pressure tube 30. The end of the piston rod 34 opposite to the piston assembly 32 is adapted to be secured to the sprung portion of vehicle 10.

Valving within the piston assembly 32 controls the movement of fluid between the upper working chamber 44 and the lower working chamber 46 during movement of the piston assembly 32 within the pressure tube 30. Because the piston rod 34 extends only through the upper working chamber 44 and not the lower working chamber 46, movement of the piston assembly 32 with respect to the pressure tube 30 causes a difference in the amount of fluid displaced in the upper working chamber 44 and the amount of fluid displaced in the lower working chamber 46. The difference in the amount of fluid displaced flows through the base valve assembly 38, the piston assembly 32, or a combination thereof.

The reservoir tube 36 surrounds the pressure tube 30 to define a fluid reservoir chamber 52 located between the tubes 30 and 36. The base valve assembly 38 is disposed between the lower working chamber 46 and the reservoir chamber 52 to control the flow of fluid between the chambers 46 and 52. When the shock absorber 20 extends in length, fluid will flow from the reservoir chamber 52 to the lower working chamber 46 through the base valve assembly 38. Fluid may also flow from the upper working chamber 44 to the lower working chamber 46 through the piston assembly 32. When the shock absorber 20 compresses in length, an excess of fluid is removed from the lower working chamber 46. Specifically, fluid flows from the lower working chamber 46 to the reservoir chamber 52 through the base valve assembly 38.

Referring now to FIG. 3, the piston assembly 32 comprises a piston body 60, a compression valve assembly 62, and a rebound valve assembly 64. The piston body 60 defines a plurality of compression fluid passages 66 and a plurality of rebound fluid passages 68, and includes a compression valve land 70 and a rebound valve land 72. The compression fluid passages 66 include an inlet 74 and an outlet 76. The rebound fluid passages 68 include an inlet 78 and an outlet 80. The compression fluid passages 66 and the rebound fluid passages 68 fluidly couple the upper working chamber 44 and the lower working chamber 46.

The piston body 60 abuts with the compression valve assembly 62, which abuts with a shoulder 82 formed on the piston rod 34. The piston body 60 also abuts with the rebound valve assembly 64, which is retained by a retaining nut 84. The retaining nut 84 and a retaining nut 86 secure piston body 60 and valve assemblies 62 and 64 to piston rod 34.

The compression valve assembly 62 includes a retainer 90, one or more spacers 92, and a valve disc assembly 94. The retainer 90 is disposed above the piston body 60 and abuts with the shoulder 82. The spacers 92 are disposed between the valve disc assembly 94 and the retainer 90 and between the valve disc assembly 94 and the piston body 60. The valve disc assembly 94 abuts with the compression valve land 70 and closes the outlet 76 of the compression fluid passages 66.

The rebound valve assembly 64 also includes a retainer 100, one or more spacers 102, and a valve disc assembly 104. The retainer 100 is disposed below the piston body 60 and abuts with the retaining nut 84. The spacers 102 are disposed between the valve disc assembly 104 and the retaining nut 84 and between the valve disc assembly 104 and the piston body 60. The valve disc assembly 104 abuts with the rebound valve land 72 and closes the outlet 80 of rebound fluid passages 68.

In the example embodiment, the damping characteristics for both rebound (extension) and compression for the shock absorber 20 are determined by the piston assembly. More particularly, the piston assembly 32 is provided as a fully displaced valving that includes valving for mid/high fluid speeds and an independent valving for low piston speeds (i.e., low hydraulic fluid flow or low fluid speed). During mid/high level speed, damping is controlled by the deflection of the valve disc assembly 94 of the compression valve assembly 62 and the valve disc assembly 104 of the rebound valve assembly 64. During low level speeds, damping is controlled by bleed passages.

In an alternative embodiment, the damping characteristics for rebound and compression of the shock absorber 20 can be determined by a combination of a piston assembly and a base valve assembly. More particularly, in a rod displaced

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valving, the base valve assembly may include a plurality of discs that control the flow fluid between the reservoir chamber and the lower working chamber. For example, during mid/high piston speed, damping can be controlled by the base valve assembly and valving at the piston. At low piston speeds, the base valve assembly can include a bleed passage to control the flow of fluid during compression, and the rebound valve assembly at the piston may include a bleed passage to control the flow of fluid during rebound.

Referring to FIGS. 4-5, an example of the valve disc assembly 94 of the compression valve assembly 62 is presented. The valve disc assembly 94 includes a plurality of discs 200 that control the flow of fluid between the lower working chamber 46 and the upper working chamber 44. The valve disc assembly 94 may be biased against the piston body 60 to seal the compression fluid passages 66. The valve disc assembly 94 includes an orifice disc 204, one or more solid discs 208, and a variable radius spring disc 212. The plurality of discs 200 each define a center bore 218, and are concentrically disposed with each other about the piston rod 34.

In the example embodiment, the orifice disc 204, the solid discs 208, and the variable radius spring disc 212 are positioned at the compression valve land 70 of the piston body 60 with the orifice disc 204 abutting against the compression valve land 70 of the piston body 60. Alternatively, the orifice disc 204 may be eliminated and a bleed orifice (not shown) may be disposed within the compression valve land 70. Accordingly, the solid discs 208 and the variable radius spring disc 212 may be positioned at the compression valve land 70 with one of the solid discs 208 abutting against the compression valve land 70 of the piston body 60.

The orifice disc 204 defines one or more orifices 220, and may also be referred to as a bleed disc. The orifice 220 forms a bleed passage referenced by arrow 224 for allowing fluid to flow between the upper working chamber 44 and the lower working chamber 46 at low piston speeds. The bleed passage 224 is open during compression and rebound, thereby allowing fluid to flow from the lower working chamber 46 to the upper working chamber 44, and vice versa.

A first solid disc 208A from among the one or more solid discs 208 is disposed over the orifice disc 204 to cover the orifices 220 of the orifice disc 204. In the example embodiment, the variable radius spring disc 212 is positioned after the first solid disc 208A. More particularly, the plurality of discs 200 are arranged such that one or more solid discs 208 are disposed between the orifice disc 204 and the variable radius spring disc 212. Accordingly, while the example embodiment illustrates one solid disc 208, more than one solid disc 208 may be located between the orifice disc 204 and the variable radius spring disc 212.

FIGS. 6 and 7 depict the variable radius spring disc 212. The variable radius spring disc, which may also be referred to as a helical disc, has an inner radius R_i and an outer radius R_o . The inner radius R_i is a fixed radius that extends from a center point CP to an inner perimeter 226 that defines the center bore 218. The outer radius R_o extends from the center point CP to an outer perimeter 228 and varies along the outer perimeter 228. Specifically, the variable radius spring disc 212 includes a maximum outer radius R_{oMAX} and a minimum outer radius R_{oMIN} . The outer radius R_o continuously changes between the maximum outer radius R_{oMAX} and the minimum outer radius R_{oMIN} such that the variable radius spring disc 212 is asymmetrical. With the varying outer radius R_o , the variable radius spring disc 212 has a spiral

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like configuration in which the outer radius R_o decreases and varies from the maximum outer radius R_{oMAX} to the minimum outer radius R_{oMIN} .

Similar to the valve disc assembly 94 of the compression valve assembly 62, the valve disc assembly 104 of the rebound valve assembly 64 may include the plurality of discs 200, and more particularly, the variable radius spring disc 212. While the valve disc assemblies 94 and 104 are described as having the same set of plurality of discs 200, the valve disc assemblies 94 and 104 may have a different number of discs that can be arranged in various suitable manners.

During a compression stroke, fluid in the lower working chamber 46 is pressurized and flows from the lower working chamber 46 to the compression fluid passages 66. The rebound valve assembly 64 restricts the flow of fluid through rebound fluid passages 68. At low fluid speeds, a controlled amount of fluid flows between the upper working chamber 44 and the lower working chamber 46 through the bleed passage 224 defined by the orifice disc 204.

As fluid pressure in the lower working chamber 46 increases, the fluid in the compression fluid passages 66 exerts a force against the valve disc assembly 94, such that the orifice disc 204 exerts a pressure onto the solid disc 208, and the solid disc 208 exerts a pressure onto the variable radius spring disc 212. As described in detail below, the stiffness of the valve disc assembly 94 varies in relation to the circumference of the valve disc assembly 94. Accordingly, the fluid pressure required to overcome a force associated with the stiffness varies circumferentially. When the force is exceeded, the valve disc assembly 94 deflects to allow fluid to flow past the valve disc assembly 94. Thus, fluid flows through the compression fluid passages 66 into the upper working chamber 44.

During a rebound stroke, fluid in the upper working chamber 44 is pressurized, and fluid flows from the upper working chamber 44 to the rebound fluid passages 68. The compression valve assembly 62 restricts the flow of fluid through the compression fluid passages 66 during the rebound stroke. Fluid flowing through the rebound fluid passages 68 is controlled by the rebound valve assembly 64. Prior to the deflection of the rebound valve disc assembly 104, a controlled amount of fluid flows from the lower working chamber 46 to the upper working chamber 44 through a bleed passage that provides damping at low fluid speeds. The fluid pressure within rebound fluid passages 68 eventually opens the rebound valve assembly 64 by deflecting the valve disc assembly 104.

The variable radius spring disc 212 promotes the asymmetrical stiffness to control the opening/closing of the valve disc assemblies 94 and 104. More particularly, by having the variable radius spring disc 212, the valve disc assemblies 94 and 104 gradually open/close in an analog wraparound manner. The operation of the variable radius spring disc 212 is described with reference to the valve disc assembly 94, and is also applicable to the valve disc assembly 104.

With reference to FIG. 7, the variable radius spring disc 212 is illustrated with the solid disc 208A, which is disposed between the variable radius spring disc 212 and the valve land 70. The surface area of the solid disc 208A that engages with the variable radius spring disc 212 varies in relation to the circumference of the variable radius spring disc 212. Accordingly, the solid disc 208A is subjected to a stiffness that varies circumferentially. As an example, sections of the solid disc 208A that align with the minimum outer radius R_{oMIN} of the variable radius spring disc 212 require less

pressure to deflect than sections of the solid disc **208A** that align with the maximum outer radius R_{OMAX} .

Accordingly, as fluid pressure increases, sections of the solid disc **208A** that are not covered by the variable radius spring disc **212** begin to open. For instance, the solid disc **208A** may begin to deflect along an outer perimeter of the solid disc **208A** starting with an area adjacent to the minimum outer radius R_{OMIN} of the variable radius spring disc **212**. The solid disc **208A** may continue to deflect toward a section adjacent to the maximum outer radius R_{OMAX} .

As pressure continues to build, sections of the solid disc **208A** that are covered with the variable radius spring disc **212** begin to open. For example, covered portions of the solid disc **208A** may begin to deflect away from the piston body **60** starting with a section having the least surface area coverage by the variable radius spring disc **212** to a section that has the most surface area coverage by the variable radius spring disc **212**.

The direction along which the solid disc **208A** deflects during a compression or rebound stroke is represented by arrow **240**. The variable radius spring disc **212** controls the deflection of the solid disc **208A** such that the solid disc **208A** circumferentially deflects away from the piston body **60** in a wraparound manner. More particularly, the solid disc **208A** deflects along a direction that corresponds to the increasing radius of the variable radius spring disc **212**.

While the wraparound deflection promoted by the variable radius spring disc **212** is described with respect to the solid disc **208A**, the other discs of the valve disc assembly **94** also deflect in a similar manner. In particular, the variable radius spring disc **212** controls the opening of the valve disc assembly **94** such that the portion of the valve disc assembly **94** that aligns with the minimum outer radius R_{OMIN} of the variable radius spring disc **212** begins to deflect away from the valve land **70** before the portion that aligns with the maximum outer radius R_{OMAX} . Due to the spiral configuration of the variable spring disc, the amount of deflection of the valve disc assembly **94** may vary such that the portion of the valve disc assembly **94** that aligns with the minimum outer radius R_{OMIN} may deflect more than the portion of the valve disc assembly **94** that aligns with the maximum outer radius R_{OMAX} .

As fluid pressure in the lower working chamber **46** decreases, the force exerted against the valve disc assembly **94** by the fluid in the compression fluid passages **66** decreases. Specifically, the valve disc assembly **94** closes the compression fluid passages **66** when the force of the valve disc assembly **94** overcomes the pressure exerted by the fluid in the compression fluid passages **66**. Similar to the opening of the valve disc assembly **94**, the variable radius spring disc **212** controls the valve disc assembly **94** such that the discs **200** gradually close the compression fluid passages **66** in a wraparound manner. For example, as pressure reduces, the portion of the valve disc assembly **94** that aligns with the maximum outer radius R_{OMAX} of the variable radius spring disc **212** begins to return to an un-deflected state to rest against the valve land **70** of the piston body before the portion that aligns with the minimum outer radius R_{OMIN} . The valve disc assembly **94** continues to seal against the valve land **70** in a wraparound manner in a direction that corresponds to the decreasing radius of the variable radius spring disc **212**. The direction along which the valve disc assembly **94** begins to close the compression fluid passages **66** is represented by arrow **244** in FIG. 7.

The variable radius spring disc **212** has a paisley or tear drop like shape in which the outer radius continuously varies. The variable radius spring disc may have other

suitable shapes in which the outer radius varies between a maximum outer radius and a minimum outer radius. For example, FIGS. **8** and **9** illustrate a variable radius spring disc **300** and a variable radius spring disc **400**, respectively. The variable radius spring discs **300** and **400** each have a maximum outer radius R_{OMAX} and a minimum outer radius R_{OMIN} . The variable radius spring disc **300** has an outer perimeter **304**, and the variable radius spring disc **400** has an outer perimeter **404**. The variable radius spring discs **300** and **400** perform in a similar manner to the variable radius spring disc **212** as described herein.

The variable radius spring disc promotes an analog opening/closing of the valve disc assembly **94** and not a digital opening/closing in which the discs move all at once to fully open or fully close the flow of fluid between the lower working chamber **46** and the upper working chamber **44**. By having an analog opening/closing, the damping characteristic of the shock absorber can be controlled between low speed and high speed operations, thereby improving the steering and handling of the vehicle. Furthermore, the gradual wrap around opening/closing of the valve disc assembly **94** prevents the discs **200** from blowing off or returning all at once, thereby improving noise, harshness, and vibration qualities of the shock absorber.

While the variable radius spring disc is described as being part of the valve disc assembly for both the compression valve assembly and the rebound valve assembly, the variable radius spring disc can provide for one valve assembly and not the other valve assembly. In addition, the variable radius spring disc may also be included in a base valve assembly.

The foregoing description of the embodiments has been provided for purposes of illustration and description. It is not intended to be exhaustive or to limit the disclosure. Individual elements or features of a particular embodiment are generally not limited to that particular embodiment, but, where applicable, are interchangeable and can be used in a selected embodiment, even if not specifically shown or described. The same may also be varied in many ways. Such variations are not to be regarded as a departure from the disclosure, and all such modifications are intended to be included within the scope of the disclosure.

Example embodiments are provided so that this disclosure will be thorough, and will fully convey the scope to those who are skilled in the art. Numerous specific details are set forth, such as examples of specific components, devices, and methods, to provide a thorough understanding of embodiments of the present disclosure. It will be apparent to those skilled in the art that specific details need not be employed, that example embodiments may be embodied in many different forms, and that neither should be construed to limit the scope of the disclosure. In some example embodiments, well-known processes, well-known device structures, and well-known technologies are not described in detail.

When an element or layer is referred to as being "on," "engaged to," "connected to," or "coupled to" another element or layer, it may be directly on, engaged to, connected to, or coupled to the other element or layer, or intervening elements or layers may be present. In contrast, when an element is referred to as being "directly on," "directly engaged to," "directly connected to," or "directly coupled to" another element or layer, there may be no intervening elements or layers present. Other words used to describe the relationship between elements should be interpreted in a like fashion (e.g., "between" versus "directly between," "adjacent" versus "directly adjacent," etc.). As used herein, the term "and/or" includes any and all combinations of one or more of the associated listed items.

Spatially relative terms, such as “inner,” “outer,” “beneath,” “below,” “lower,” “above,” “upper,” and the like, may be used herein for ease of description to describe one element or feature’s relationship to another element(s) or feature(s) as illustrated in the figures. Spatially relative terms may be intended to encompass different orientations of the device in use or operation in addition to the orientation depicted in the figures. For example, if the device in the figures is turned over, elements described as “below” or “beneath” other elements or features would then be oriented “above” the other elements or features. Thus, the example term “below” can encompass both an orientation of above and below. The device may be otherwise oriented (rotated 90 degrees or at other orientations), and the spatially relative descriptors used herein interpreted accordingly.

What is claimed is:

1. A shock absorber for a vehicle comprising:
 - a pressure tube defining a fluid chamber;
 - a piston disposed within the fluid chamber, the piston dividing the fluid chamber into an upper working chamber and a lower working chamber, the piston defining a plurality of passages extending through the piston between the upper working chamber and the lower working chamber; and
 - a valve disc assembly supported on the piston and controlling a flow of fluid between the upper working chamber and the lower working chamber through the plurality of passages, the valve disc assembly including a variable radius spring disc among a plurality of discs, wherein
 - the variable radius spring disc has an outer radius that increases continuously and circumferentially from a first circumferential point to a second circumferential point, along an outer perimeter of the variable radius spring disc, and then makes a convex turn followed by a transition from the second circumferential point via a concave turn back to the first circumferential point, and
 - the valve disc assembly creates a stiffness that varies in relation to a circumference of the variable radius spring disc such that an actuation of the valve disc assembly with respect to the piston varies circumferentially.
2. The shock absorber of claim 1 wherein the variable radius spring disc has an asymmetrical shape.
3. The shock absorber of claim 1 wherein the variable radius spring disc has a maximum outer radius and a minimum outer radius, and a given outer radius measured from a center point to a given point along the outer perimeter has a value between the maximum outer radius and the minimum outer radius.
4. The shock absorber of claim 1 wherein:
 - the plurality of discs of the valve disc assembly further includes an orifice disc and one or more solid discs, and the plurality of discs are arranged such that at least one of the one or more solid discs is disposed between the orifice disc and the variable radius spring disc.
5. The shock absorber of claim 1 wherein:
 - the plurality of discs actuate away from the piston along a first direction to allow fluid flow between the upper working chamber and the lower working chamber, and actuate toward the piston along a second direction opposite to the first direction to prevent fluid flow between the upper working chamber and the lower working chamber,
 - the first direction corresponds to a direction along which the outer radius of the variable radius spring disc increases, and

the second direction corresponds to a direction along which the outer radius of the variable radius spring disc decreases.

6. The shock absorber of claim 1 wherein:

the piston includes a support land that circumferentially extends along a surface of the piston, and

the plurality of discs of the valve disc assembly further includes an orifice disc and one or more solid discs, the plurality of discs is disposed at the support land and is arranged such that the orifice disc is disposed on the support land and at least one of the one or more solid discs is disposed between the orifice disc and the variable radius spring.

7. The shock absorber of claim 1 wherein:

the variable radius spring disc has a maximum outer radius and a minimum outer radius, and

fluid pressure required to deflect the valve disc assembly from the piston is greater at a portion of the valve disc assembly that aligns with the minimum outer radius than a portion of the valve disc assembly that aligns with the maximum outer radius.

8. The shock absorber of claim 1 wherein the stiffness of the valve disc assembly increases as the outer radius of the variable spring disc increases.

9. The shock absorber of claim 1 wherein:

the valve disc assembly deflects away from the piston along a direction that corresponds to an increase in the outer radius of the variable radius spring disc as fluid pressure increases in the plurality of passages, and

the valve disc assembly actuates to seal the plurality of passages along a direction that corresponds to a decrease in the outer radius of the variable radius spring disc as fluid pressure decreases in the plurality of passages.

10. A shock absorber for a vehicle comprising:

a pressure tube defining a fluid chamber;

a piston disposed within the fluid chamber, the piston dividing the fluid chamber into an upper working chamber and a lower working chamber, the piston defining a plurality of passages extending through the piston between the upper working chamber and the lower working chamber; and

a valve disc assembly engaging the piston and controlling a flow of fluid between the upper working chamber and the lower working chamber through the plurality of passages, the valve disc assembly including a plurality of discs, wherein the plurality of discs includes a helical disc, wherein

the helical disc has an outer radius that increases continuously and circumferentially from a first point to a second point, along an outer perimeter of the helical disc, and then makes a convex turn followed by a transition from the second point via a concave turn back to the first point, and

the valve disc assembly has a stiffness that circumferentially varies based on the outer radius of the helical disc such that the valve disc assembly circumferentially actuates in a wraparound manner along the piston.

11. The shock absorber of claim 10 wherein the stiffness of the valve disc assembly is proportional to a surface area of the helical disc such that the stiffness increases as the surface area of the helical disc increases.

12. The shock absorber of claim 10 wherein the stiffness of the valve disc assembly increases as the outer radius of the helical disc increases and decreases as the outer radius of the helical disc decreases.

13. The shock absorber of claim 10 further comprising:

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a reservoir tube; and
 a base valve assembly, wherein
 the pressure tube is housed in the reservoir tube,
 the pressure tube and the reservoir tube define a reservoir
 chamber, 5
 the base valve assembly controls the flow of fluid between
 the lower working chamber and the reservoir chamber,
 and
 the base valve assembly includes a second helical disc
 among a second plurality of discs, the second helical 10
 disc has an outer radius that varies circumferentially
 along an outer perimeter of the second helical disc.
14. The shock absorber of claim 10 wherein:
 the plurality of discs of the valve disc assembly further
 includes an orifice disc and one or more solid discs, and 15
 the plurality of discs are arranged such that at least one of
 the one or more solid discs is disposed between the
 orifice disc and the helical disc.
15. The shock absorber of claim 10 wherein:
 the plurality of discs actuate away from the piston along 20
 a first direction to allow fluid flow between the upper
 working chamber and the lower working chamber, and
 actuate toward the piston along a second direction
 opposite to the first direction to prevent fluid flow
 between the upper working chamber and the lower 25
 working chamber,
 the first direction corresponds to a direction along which
 the outer radius of the helical disc increases, and
 the second direction corresponds to a direction along
 which the outer radius of the helical disc decreases. 30
16. The shock absorber of claim 10 wherein the helical
 disc has a maximum outer radius and a minimum outer
 radius, and fluid pressure required to deflect the valve disc
 assembly at the maximum outer radius of the helical disc is
 greater than at the minimum outer radius of the helical disc. 35
17. A shock absorber for a vehicle comprising:
 a pressure tube defining a fluid chamber;
 a piston disposed within the fluid chamber, the piston
 dividing the fluid chamber into an upper working 40
 chamber and a lower working chamber, the piston
 defining a compression passage and a rebound passage,
 wherein the compression passage and the rebound

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passage extend through the piston between the upper
 working chamber and the lower working chamber;
 a compression valve assembly engaging the piston,
 wherein the compression valve assembly controls a
 flow of fluid through the compression passage; and
 a rebound valve assembly engaging the piston and con-
 trolling a flow of fluid through the rebound passage,
 wherein
 at least one of the compression valve assembly and the
 rebound valve assembly includes a variable radius
 spring disc among a plurality of discs,
 the variable radius spring disc has an outer radius that
 continuously increases from a first point to a second
 point along an outer perimeter of the variable radius
 spring disc, and then makes a convex turn followed by
 a transition from the second point via a concave turn
 back to the first point, and
 the at least one of the compression valve assembly and the
 rebound valve assembly has a stiffness that circumfer-
 entially varies based on the variable radius spring disc.
18. The shock absorber of claim 17 wherein the stiffness
 of the at least one of the compression valve assembly and the
 rebound valve assembly increases as the outer radius of the
 variable radius spring disc increases and decreases as the
 outer radius of the variable radius spring disc decreases.
19. The shock absorber of claim 17 wherein:
 the plurality of discs actuate away from the piston along
 a first direction to allow fluid flow between the upper
 working chamber and the lower working chamber, and
 actuate toward the piston along a second direction
 opposite to the first direction to prevent fluid flow
 between the upper working chamber and the lower
 working chamber,
 the first direction corresponds to a direction along which
 the outer radius of the variable radius spring disc
 increases, and
 the second direction corresponds to a direction along
 which the outer radius of the variable radius spring disc
 decreases.
20. The shock absorber of claim 17 wherein the variable
 radius spring disc has an asymmetrical shape.

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